DEPARTMENT OF NOTES, REVIEWS, ETC.

It is the purpose, in this department, to present from time to time brief original notes, both of methods of work and of results, by members of the Society. All members are invited to submit such items. In the absence of these there will be given a few brief abstracts of recent work of more general interest to students and teachers. There will be no attempt to make these abstracts exhaustive. They will illustrate progress without attempting to define it, and will thus give to the teacher current illustrations, and to the isolated student suggestions of suitable fields of investigation.—[Editor.]

Summary of the Elements in the Reproductive Process

Teachers of Biology often have occasion to devise special methods to put before students, in a single view, the various elements in a complex biological concept. Such a device, if successful, is in reality a summary of the essential factors or parts of the process or structure, together with an expression of the relations between the factors, so formulated that the pupil may successfully visualize them in their proper proportions and be conscious of them in his complete synthesis of the concept. Such a device is peculiarly essential with certain classes of pupils who, after an analysis of such a complex, refuse to re-synthesize *all* the elements—but allow one or two major factors to usurp the meaning of the whole. The need of this sort of aid is apparent especially in the study of the evolutionary processes where the comparative element enters largely.

Reproduction is an illustration of such a complex and significant phenomenon in biology. It is so varied in the different groups of plants and animals, and includes or has associated with it so many different elements at the different levels of life that it is almost impossible to bring even the most important of these into a scheme in such a way that the student may grip their interrelations, and it is not possible in any scheme of reasonable complexity to include all the related facts.

The device presented herewith is submitted purely as a pedagogical scheme summarizing the main features of the process of reproduction in plants and animals, and showing at least a portion of the evolutionary tendencies connected with the fundamental func-

tion. It is offered to assist teachers and not as a contribution to knowledge.

The following brief discussion of the major items connected with reproduction, as exemplified by the two series of organisms, will serve to explain and elaborate the heads included in the table (Plate VI).

1. *The essential nature of reproduction,* no matter how simple nor what additional processes and complications may be introduced, is *division.* The divisions may be equal or unequal, may be of single-celled organisms or of complex; but without any exception reproduction always involves the division of parental material to make offspring. New individuals are thus formed at the expense of the old. It is always in contrast with assimilation and growth, and means a sacrifice of the individual structure that has been builded up by these processes. This reproduction or division resulting from growth is due apparently to some stimulus which is normally brought on by the accumulation of internal materials and the near culmination of internal processes and powers which we describe by the term maturity. The exact nature of these stimuli we do not know. (See first column of chart.)

2. *Primary Kinds of Division* (*Reproduction*). There are two main types of parental division, depending on the complexity of the organisms (second column):—

(a). In unicellular organisms reproduction is a matter of nuclear and cell division merely. Such daughter cells separate and lead individual lives. The division of one cell into two or more cells is at the same time the division of an individual one-celled parent organism into two or more individual offspring. The cell being the body of the organism, reproduction is at once a bodily division and a nuclear or cell division. This is reproduction at its simplest. Clearly in such a case as this the daughter organism, which is a small cell, reaches maturity by a simple process of growth into a large cell, whereupon reproduction may occur again, when the stimulus of maturity becomes operative.

(b). By far the greater number of our plants and animals are, however, multicellular in their adult stage. They have reached this condition by a long series of nuclear and cell divisions in which

the cells *did not separate* into distinct individuals, but remained together as parts of a more complex individual. Division of such an organism as this is a somewhat different thing from what was described in (a). The many-celled organism may divide bodily into two or more smaller, but many-celled, offspring. This is analogous to the division in (a) in that it is a mass division. It differs from (a) in that it is not at all a cell division.

Again the multicellular organisms may reproduce by freeing, through division, single-celled offspring, which are, of course, the immediate product of cell and nuclear divisions taking place in a certain line of cells in the body of the multicellular parent. These divisions are homologous with the reproduction described in (a) in that these reproductive cells are formed by nuclear and cell division. The process differs from (a) only in the fact that the dividing cells that form the offspring are harbored in a many-celled body. We may say then that reproduction in (a), with its double aspect of cell division and bodily division in one operation, has become specialized in (b) into two separate possible operations, one of the multicellular body and the other of the unicellular germ cells, contained in that body.

3. *The Ratio in Size of the Parental Body to That of the Offspring.* In its simplest form the division of the parent, whether one or many-celled, into new individuals may be considered as producing two practically equivalent offspring, each of which has one-half the endowment of original parental material. So far as this ratio is concerned the condition is much the same in the unicellular organisms and in those multicellular ones,—as flatworms, naidiform oligochetes, and the like,—in which there is division into essentially equivalent daughters. In both cases we may fairly say that the parental organism is completely destroyed in the act of reproduction. Strictly speaking, there is no parent left, and the two offspring formed are mutually at the highest advantage possible to offspring in that they only have to double their material to be at complete maturity of individuality. (See third column of chart.)

4. *Depreciation in the Volume of the Reproductive Units (Offspring).* The method just described is at a maximum of sacrifice on the part of the parent with maximum biological advan-

tage to a limited number of offspring. It leads to well endowed offspring, brief periods of immaturity, numerous reproductions, and impermanent individuality on the part of the parent. From this simple condition as a starting point there are, in practice, two departures found in organisms whereby a certain form of increase of effectiveness is obtained: (1) there may be a division of the entire parent into many offspring, by fragmentation, sporulation, etc., which continues the complete destruction of the parent as in the former case, but reduces the endowment of each offspring. The compensating fact is the increased number of offspring. This device increases the period of immaturity and in consequence pushes apart the successive reproductive generations; (2) the second case is illustrated by a budding process such as is seen in the yeast cell or in hydra,—or by the condition to be described later for still higher forms. In these the parent is not completely destroyed, and the one or many offspring are reduced correspondingly in volume and in initial vital efficiency. This diminution in volume may be such that the offspring of a multicellular organism may consist of a single cell. This is clearly a much more economical mode of reproduction with very much less drain on the parent; it allows a more continuous parental existence with an increased emphasis on permanency of individuality; it makes possible frequent or even continuous reproductive activity, with more numerous offspring.

5. *Depreciation in Value Accompanying Depreciation in Volume.* It will be realized in connection with the above that the economy and gain through safeguarding the parent and in the capability of producing many offspring has been purchased at the expense of the amount of the original parental material going to each offspring. As the result of this reduction in volume the offspring necessarily has a longer, more difficult course to run in coming to reproductive maturity. This means that the decreased volume entails a decreased present biological value in the reproductive units. The more the offspring differs from the parent the more extended and difficult is its task in reaching maturity. The reduction in volume and in value is greatest in our higher, more complex multicellular animals and plants in whose case the new offspring is merely a single cell at the outset. This condition is il-

lustrated both by the spores and gametes. In the gametes, which are reproductive units that normally unite before development, and in the spores, at least of the higher plants, there is another most interesting reduction to which further reference is made in Section 9. Here the offspring is not merely reduced to one cell; the number of chromosomes in the nucleus of that cell is reduced to one-half the number characteristic of the individual body cells of the species. One further step in the depreciation in volume is seen in the sperm (or male) cells in most animals and plants. In addition to the loss of one-half its chromosomes, the male cell is much reduced in the amount of cytoplasm.

6. *The Necessity of Restoration.* The depreciation of the one-celled offspring of the higher animals and plants described in the preceding section is shown further by the fact that these new offspring are frequently unable to enter, as soon as they are formed, upon the series of cell divisions and other changes which have been described as necessary to maturity. Their further development seems to be checked in part by the excessive reduction they have suffered. This is very often true of spores, which may not undertake to germinate for some time after their formation, even though external conditions seem favorable. The gametes, eggs and sperm, are normally even more incapable of entering at once on the stages that lead to maturity, without external help. It is even more true of the sperm than of the egg. The sperm, it will be recalled, is like the egg in having only one-half endowment of chromosomes; it has also lost the major part of its protoplasm, of which the egg has an abundance. The spores and the eggs of many species may develop rather promptly, but so far as we know the sperm is so reduced in the typical higher plants and animals as to be wholly incapable, in itsef, of developing into the adult. (See column six of chart.)

It would seem, therefore, that the tendency to economize parental expenditure and to increase the number of offspring had overreached its mark,—defeating in large degree its prime result of economic reproduction. At this point in nature we find a series of recuperative processes by which these reduced reproductive bodies are given the power to resume their activities and are restored ap-

parently to a vigor which enables the single cell to develop, in proper order, all the essential characteristics of the species to which it belongs. Because of these restorative processes these single-celled reproductive units cease to be merely single cells; they are potential adults.

7. *Methods of Restoration.* This need of restoration, suggested by the great reduction in the parental substance—the cytoplasm and chromatin—that goes to each of the unicellular offspring and reinforced by the fact that they are often unable at once to develop, is met in nature in two or three principal ways.

In the first place, and most simply, it frequently happens that the offspring may regain this power of developing to the mature state by a mere season of rest or quiescence, without any other change of condition. This is quite commonly true of the spores. It is not always true that the spores need such a rest period, however; they may often develop directly. (See column seven of chart.)

Secondly, in addition to the mere lapse of time the spores, after leaving the parental tissues, are undoubtedly subjected to decided changes in respect to moisture, temperature, and other important environmental conditions. These changes may themselves, rather than the mere rest, be the stimulating and restoring agency. We know that decided changes in environmental conditions do stimulate renewed activity in vital processes. This may be analogous to the artificial stimuli that arouse unfertilized eggs into action as described below.

In the third place, the gametes usually demand more than rest. In this type of reproductive units, where chromosome reduction is well nigh universal, it is ordinarily essential that two gametes (offspring)—each containing one-half the specific number of chromosomes—shall unite and bring the contents of both the cells into one. Such a united cell, which is no longer a single reproductive body or offspring, but rather a fusion of two offspring, has the power of development, which did not reside in either of the original cells. This is called conjugation or fertilization. It frequently happens that a period of rest is also needed in connection with these unions, though this is not the rule.

Finally, it has been discovered by experiments that this restoration and immediate power of development of gametes (the egg particularly) can be secured in some organisms in various artificial ways. These consist for the most part in applying to the gametes certain conditions,—changed mechanically or chemically from the normal. This is known as artificial *parthenogenesis,*—and means that certain eggs which would not ordinarily begin development without union with another cell may be caused to develop by chemical and mechanical stimuli. It will be seen that this is analogous to the condition described in the second type of restoration above, by which spores may come to the point of developing through changed external conditions. The same power is sometimes normally possessed by the larger of the two gametes,—the ovum (parthenogeneses: section 9).

8. *Conjugation (Isogamy).* In that form of restoration of power to the offspring, in which gametes unite and, by fusing two half-sets of chromosomes, regain the full complement of chromosomes, the most simple form has uniting gametes in which no difference is distinguishable. So far as we can see, each of the offspring entering into the fusion is exactly equivalent to the other. Each has suffered equal reduction as compared with the original parent, both in protoplasmic substance and in chromosomes. We cannot properly use here the terms male and female, nor fertilization, nor sex. The fusion is mutual and there seems no differentiation of function in the gametes. This is known as *isogamy* or *conjugation.* In some cases the conjugation is *facultative;* that is, the gametes usually conjugate, but if this does not occur, they may after a period of rest develop without it.

9. *Differentiation Among the Gametic Offspring (Heterogamy).* In many species of organisms the same individual may produce two different kinds of offspring or gametes. In such cases the gametes may be nearly alike, differing only slightly in size. In other species there may be great difference in size and behavior. At the extreme of this differentiation we have the two types of offspring known as *ova* and *sperms.* Characteristically, the eggs are unicellular offspring, which are large, spherical, well nourished, and sluggish cells, with much protoplasm, but only one-half the specific

number of chromosomes at maturity. The sperms, on the other hand, are usually actively motile cells, of very various shape, though not spherical like the egg. They are much reduced in protoplasm, but they have the same number of chromosomes as the ova,—that is, one-half the specific number. (See column four of chart).

This condition introduces *sex*. The ova are known as *female* and the sperm as *male*. The union of the ova and sperm, in pairs, which is usually necessary to restore the power of development, is called *fertilization*. In some species the ova may develop without union with the male cell. This is known as *parthenogenesis,* and it is possible that this ability represents the action of some condition of the parental body, analogous to hormone action, which substitutes some other stimulant for that of the male cell, which is the usual or normal one.

It is necessary to insist that the eggs and the sperm are the real *offspring,* and that the act of reproduction in the female is the production of eggs; that reproduction in the male is formation of sperm; and that fertilization, which is union, is not reproduction at all, but the direct opposite of it. It is in part at least a restorative process following upon the reduction and depreciation of the gametes in reproduction, and instituting a series of cell divisions which provides both for the new parental body and the new generation of reproductive cells (offspring) which are derived from it.

10. *Differentiation of Organs of Sex.* In the simplest state of the formation of the reproductive units, especially before these units themselves are sharply different, the organs or structures in plants and animals which produce the two kinds of offspring are not only in the same individual *(hermaphroditism),* but they are much alike, except for the fact that the gametes they produce differ more or less. There is, however, a perfectly clear tendency for the organs and structures connected with the production and distribution of eggs (female offspring) and the sperm (male offspring) to become different,—and often very markedly different, even when they occur in the same individual,—quite as diverse indeed as are the offspring which they produce. This is a quite common kind of hermaphroditism, in which a single plant or animal develops two dif-

ferent, and often very complex, sets of sex structures to produce and take care of the two kinds of offspring so as to insure their fertilization and development. It is illustrated in earthworms, snails, and many other organisms. Ordinarily this union is supposed to be not between the offspring of the same parent, but of different parents *(cross-fertilization)*. Doubtless self-fertilization is also frequent.

11. *Diversification of Parents (Sex-dimorphism).* The problem and function of producing and caring for ova is so different from that of producing and caring for sperm that such a differentiation as we have seen in the last section takes places in the organs that do the work. This differentiation does not in the majority of animals and plants stop here. The differentiation of sex, first seen in the offspring (eggs and sperm) and then in the organs producing them (ovaries and spermaries), comes to show in the individuals which bear the organs; and male individuals come to be differentiated from female individuals as much as ovaries differ from testes or ova from sperm. (See column five of chart).

Among animals and plants can be found all degrees of these sex differences. We have individuals that produce ova and have female organs and characteristics at one period of life, and later are males and produce sperm. In others, permanently male or female, the external differences are so slight that dissection of the organs of reproduction alone can determine the sex of the parent. In still others there are such striking differences between the sexes that they would not be regarded as belonging to the same species of organisms from structure alone. This is the condition in most of the higher organisms, and is particularly striking in all the higher animals. The differences between the male and female in man, in birds, in many insects and spiders are matters of common observation.

12. *Parental Care of Offspring.* The depreciation of offspring in the interest of economy to the parent and of increased number of offspring, coupled with the resulting need of restoration by fertilization or some other device, has led to other most important biological results. The longer course over which the offspring must go to reach maturity, the diversification of the gametes, and the con-

sequent diversification of the male and female parents furnish the biological groundwork for very interesting adaptations for mating, home-making, parental care. These adaptations may be structural, instinctive, emotional, or intellectual. These are among the highest and most stimulative of the biological phenomena,—upon both parents and offspring. Because of such conditions the care-taking, sympathetic, social aspects of parents are emphasized, the period of filial dependence is made longer and more fruitful through association with parents, and the motives for social life and development are introduced. It is not easy for the student to exaggerate the evolutionary importance of this group of phenomena correlated with reproduction, and common in many animals of the higher groups.

13. *Combination of the Reproductive Methods in One Individual.* In what has been said the process has been treated as though a given species of organisms had only one mode of reproducing. As a matter of fact we often find that a plant or animal will for a period show some form of mass division (vegetative reproduction)

EXPLANATION OF PLATE VI

The scheme represents an effort to put in tabular form some of the more important relations suggested in the discussion. The vertical columns indicate certain of the classes of facts connected with reproduction. The horizontal subdivisions express some of the important variations in respect to the particular phenomena named at the head of the columns. In a general way the category nearer the bottom of the page at each step is looked upon as the lower, and as giving rise to that above it. For example, the following free translation will illustrate what is conceived as the simplest condition from which others have arisen: "Direct mass-division of unicellular parents into (2) offspring, equal to one-half the parent and equal to each other, which demand no special restoration to enable them to begin the new growth, is exemplified by fission among the Bacteria." The signs + and — in column six indicate "requiring" and "not requiring" restoration respectively.

It is not intended always to imply that the subdivisions in a brace are strictly logical subdivisions of the category preceding. For example: "Many O." near the bottom of the fourth column manifestly cannot be a subdivision of "O = ½ parent"; it is rather thought of as a derivative and extension of the fission process, whereby "2 equal O." are produced from the one-celled parent.

ESSENCE OF REPRODUCTION	a. CELLULAR b. BODILY (INDIVIDUAL)	RATIO BETWEEN PARENTS and OFFSPRING	DIVERSIFICATION OF THE REPRODUCTIVE UNITS	DIVE… O… PAR…

- DIRECT MASS-DIVISION of PARENTS
  - Multicellular Bodies
    - DEPRECIATION — PARENTS MUCH LARGER than Offspring
      - O. Unicellular Unequal — from — 2 DI… PA… / 1 PA…
      - O. Unicellular Equal — 1 PA…
      - O. Multicellular Equal (or unequal) — 1-Many
    - O. = ½ PARENT
      - O. Equal : 2
  - Unicellular Bodies
    - PARENTS MUCH LARGER than Offspring
      - Two or More O.
        - O. Unequal — DIF. PA… BUT S… / SAME …
        - O. Equal
    - O. = ½ PARENT
      - Many O.
        - Unequal
        - Equal -- (SPORULATION)
      - 2 Equal O. (FISSION)

ATION UNITS	DIVERS'N OF PARENTS	LOSS OF POWER and NEED OF RESTORATION in Offspring	METHOD:- 1. REST 2. UNION	TYPE OF REPRODUCTION
} from	2 DIVERSE PARENTS	+Restoration	UNION	Dimorphic Sexuality.
		-Restoration		Parthenogenesis-BEES. APHIDS.
	1 PARENT	+Restoration	UNION	Hermaphrodite E. WORMS
r	1 PARENT	+or-Restoration		Spore Formation
r } al)} 1-Many		+Restoration	REST	Tubers
		-Restoration		Budding; E.G. HYDROZOA.
		-Restoration		Flat Worms (FISSION)
qual	DIF. PARENTS BUT SIMILAR	+Restoration	UNION	Eudorina.
	SAME PARENT	+Restoration	UNION	Vorticella.
ual		+Restoration	UNION	Some Heliozoa
			REST	Colpoda. Ephelota.
		-Restoration		Yeast etc. Budding
qual		+Restoration	UNION	Plasmodium.
al-- (ULATION)		+Restoration	UNION of TWO	Chlamydomonas THE SMALL ZOOSPORES
			UNION of MANY	Actinosphaerium MYXOMYCETES
			REST	Scenedesmus ACTINOSPHERIUM
		+or-Restoration		Yeast:- ASCOSPORES
ISSION)		+Restoration	UNION PERM'T	Desmids
			UNION TEMP'Y	Paramecium
			REST	Euglena
		-Restoration		Bacteria (FISSION)

PLATE VI

or spore formation, and will then, owing to some change of conditions internal or external, enter upon reproduction by gametes. The same individual, thus, at different periods of life or with different stimuli in the way of temperature or nutrition and the like, may combine the advantages outlined in the preceding sections in the various special methods of securing the reproductive act. The possession of these several methods of reproducing of course makes possible a much more equable and adequate response to the varying environmental pressure.

14. *Alternation of Generation,—a Combination of Reproductive Methods in Different Individuals Constituting a Single Life-Cycle.* Another form of combination of reproductive methods than that described in section 13 is found in most of the complex plants and in many types of animals. It consists essentially in, we may say, a reproduction by gametes, in which the egg is fertilized by the sperm in the usual way resulting in a type of individual which we shall call "A"; individuals of the type "A" become mature and do not have the power to produce gametes at all, but, on the contrary, they may bud, or divide vegetatively, or form spores; when these new individuals come to their reproductive maturity they are different, often very different, in appearance from individuals "A", and may be called "B". This second type of organisms in its turn cannot reproduce as "A" reproduced, but reproduces by gametes, and the embryo resulting from their union matures into a type like the original "A". We have thus come round to the same point in the "cycle" at which we started, and in doing so we have had two succeeding types of individuals in the same species and two different methods of reproduction regularly alternating. "A" produces non-sexually individuals "B", and "B" reproduces sexually individuals "A". In coelenterates "A" is the tubular type, multiplies by budding and ultimately produces the medusoid individuals "B". These latter reproduce by eggs and sperm, from the union of which the tubular hydroid forms are again produced.

In plants, "A" is known as the *sporophyte generation,* which produces spores. When the spores germinate they produce the new and very different *gametophyte generation,* which reproduces by the

formation of gametes, male and female. The union of these initiates the sporophyte generation again. (See text Fig. 1.)

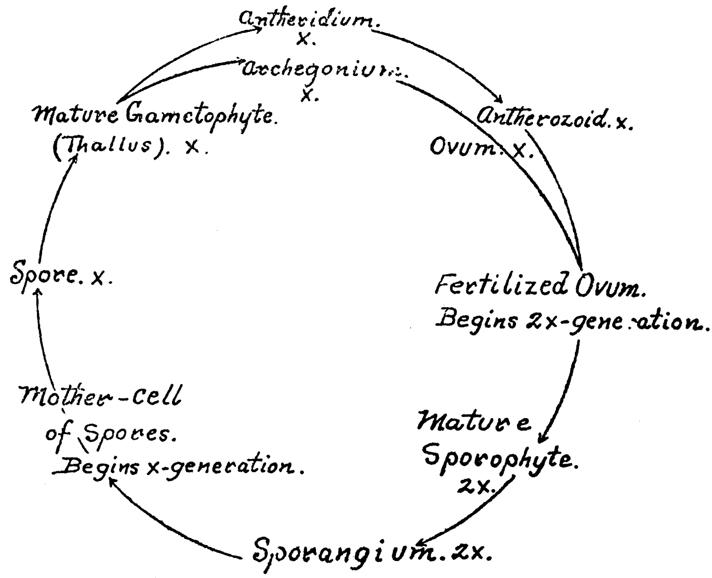

Fig. 1.—A diagram to illustrate the life-cycle, the alternation of generation including the relation of the x and 2x condition of the chromosomes, in one of the higher plants (e. g. a fern). The fertilized ovum is the beginning of the sporophyte generation. The spore is the beginning of the gametophyte generation.

15. *Relation of the Chromosome Reduction to the Alternation of Generation.* The two kinds of gametes possess a number of chromosomes characteristic of the species. This number is spoken of as x. When they unite the chromosomes of male and female gametes do not lose their integrity, but the resulting embryo has the double number of chromosomes, or 2x. As cell division occurs and the resulting plant becomes multicellular, the number of chromosomes is not reduced, but all the body cells of the new plant (sporophyte) have 2x chromosomes. This remains true until the nuclear divisions immediately preceding the formation of the spores, or non-sexual reproductive bodies. At this time there is a reduction to one-half the number, and thus the spores themselves contain nuclei with only the x number of chromosomes.

As the spore germinates and the new multicellular generation (gametophyte) is produced this condition is unchanged; and since the gametes are formed from the gametophyte they have likewise the x chromosomes, as we saw at the beginning of this section. In the union of the gametes the double number is again restored.

The condition is pictured in the accompanying diagram (Fig. 1). The relative length and importance of these two generations is very varied in the different groups of plants, but the alternation of generation, and the distinctive reduction and restoration of chromosomes by which the generations are marked are very constant.

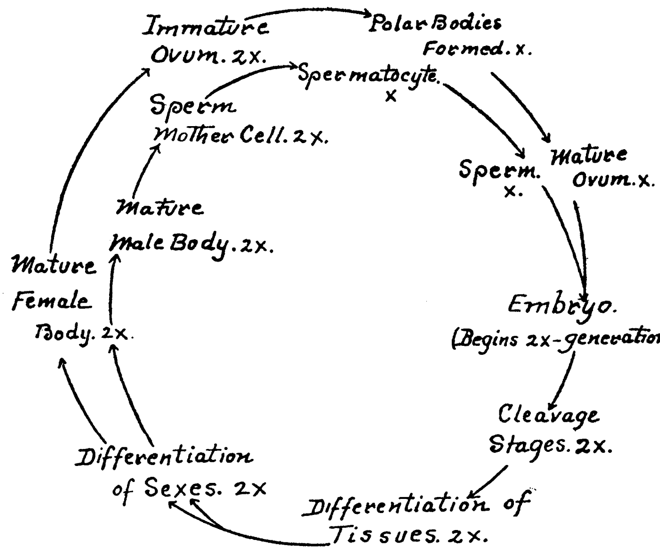

Fig. 2.—A diagram to illustrate the life-cycle and the x and 2x state of the chromosomes in higher animals. It will be seen that the x stage is very brief.

A condition somewhat analogous is seen in diagram, Fig. 2, which represents the condition in higher animals. Whether it is more than analogy we are not now prepared to say. The ordinary body of the animal is made up of cells with 2x chromosomes. This continues up to the time of the formation of the gametes. In their formation and maturation the number is normally reduced to x, immediately to be doubled upon the union of the gametes in fer-

tilization. This reduction and doubling of the chromosomes is strongly believed to be closely connected with the hereditary transmission of characteristics from two parents, and seems to have to do with the changes in the germ plasm that produces variation within the offspring of the same pair of parents.

T. W. Galloway.

The Growth of a Compound Eye

As is well known to students of insect life, there is a period between the larval and adult stages of development when important structural changes take place. For instance, take one particular type of organ, such as the eye. In a moth larva such as the Tussock, *Notolophus leucostigma,* the larva has several single eyes grouped on each side of the head. Somewhere between the time of its entering upon the pupal stage and its emergence therefrom as an adult it exchanges these simple larval eyes for an elaborate pair of compound eyes. How it does this, and what becomes of the old larval eyes, is a process so well hidden from view in the pupal case that only cytological work can reveal the secrets.

When ready to pupate the larvae of most moths seek various sheltered positions in which they undergo their final molt or shedding of the larval cuticula. This leaves the hypodermal (epidermal) cells of the creature raw, under which conditions they exude a fluid which hardens and forms the pupal case.

As most individuals of a brood undergo their stages at similar intervals one may by collecting a number of pupae at this stage get material for studying not only the stages of the eye, but of other structures as well. By selecting individuals, at say two-day intervals from the first day of pupation onward, we will get a series showing the progressive development of the parts.

The pupa so selected should be opened in the back by a sharp instrument to allow the rapid penetration of the killing and fixative fluids. If any particular part of the tissue is wanted, it is necessary to be very careful, in making openings, not to injure or deform the tissues in the immediate vicinity.

During the pupal life, two very important and entirely opposite processes are necessarily very active. One is the breaking